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13. ABSTRACT (Maximum 200 words)

A broad, multidisciplinary program has been pursued in the area of quantum computation and information. Principal accomplishments include an experiment to localize atoms within a high quality factor optical cavity for the implementation of quantum logic and the realization of quantum teleportation. Theoretical work has shown how to accomplish quantum computations of arbitrary length reliably, even with error prone quantum gates and memories, and has significantly improved calculations of the required error thresholds. Quantum error correction has been analyzed within the larger framework of quantum feedback control. New types of physical systems have been investigated for quantum computation that would be intrinsically robust to environmental disturbances. Bridges between experiment and theory have been built by way of large-scale simulations of quantum circuits on classical computers, including quantum Monte Carlo techniques. These simulations allow for detailed investigations of the impact of errors and allow for validation of various models of actual physical systems. New algorithms have been developed for simple (few-bit) quantum computers. Diverse "nonstandard" models for quantum computation have been investigated, including nonlinear quantum mechanics for quantum computation.

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QUIC -
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2001 Project Summary
Quantum Information and Computation
California Institute of Technology
Project Website:
http://theory.caltech.edu/~quic/index.html
Additional project information provided by the performing organization

Objectives

The long range goal of this program of research has been to build and to operate devices that can store and process information in the quantum states of matter. The motivation is that such devices, if they can be made to function, will be able to solve interesting and difficult problems that cannot be solved with conventional classical computers. The scope and goals of this research program have been as follows:

- Develop and explore new ideas for the physical implementation of quantum gates in the laboratory
- Broaden the range of problems that are known to be efficiently solvable using quantum computation
- Design efficient networks of quantum gates that can solve interesting problems
- Develop methods to improve the reliability of a quantum computer that operates under realistic noisy conditions
- Develop a sequential simulator to validate and optimize models and circuits for quantum computers
- Fabricate devices and conduct experimental studies of their performance
- Develop quantum networks for distributed quantum computation and communication.

Over the duration of the QUIC program supported by DARPA and administered by ARO we have made significant progress on all these fronts. Major accomplishments of the program include the discovery that quantum computers can actually be constructed from imperfect components and made to work reliably by way of fault tolerant architectures and the first realization of unconditional quantum teleportation. These and other milestones have been discussed in the yearly reports to ARO and DARPA, as well as the publications from the QUIC collaboration, which are compiled in the following sections.

Approach

The general structure of the QUIC collaboration is illustrated in Figure 1. In August 1996, our collaboration embarked upon a broad-based program of investigation in Quantum Information Science, with details about specific activities provided in the following sections.

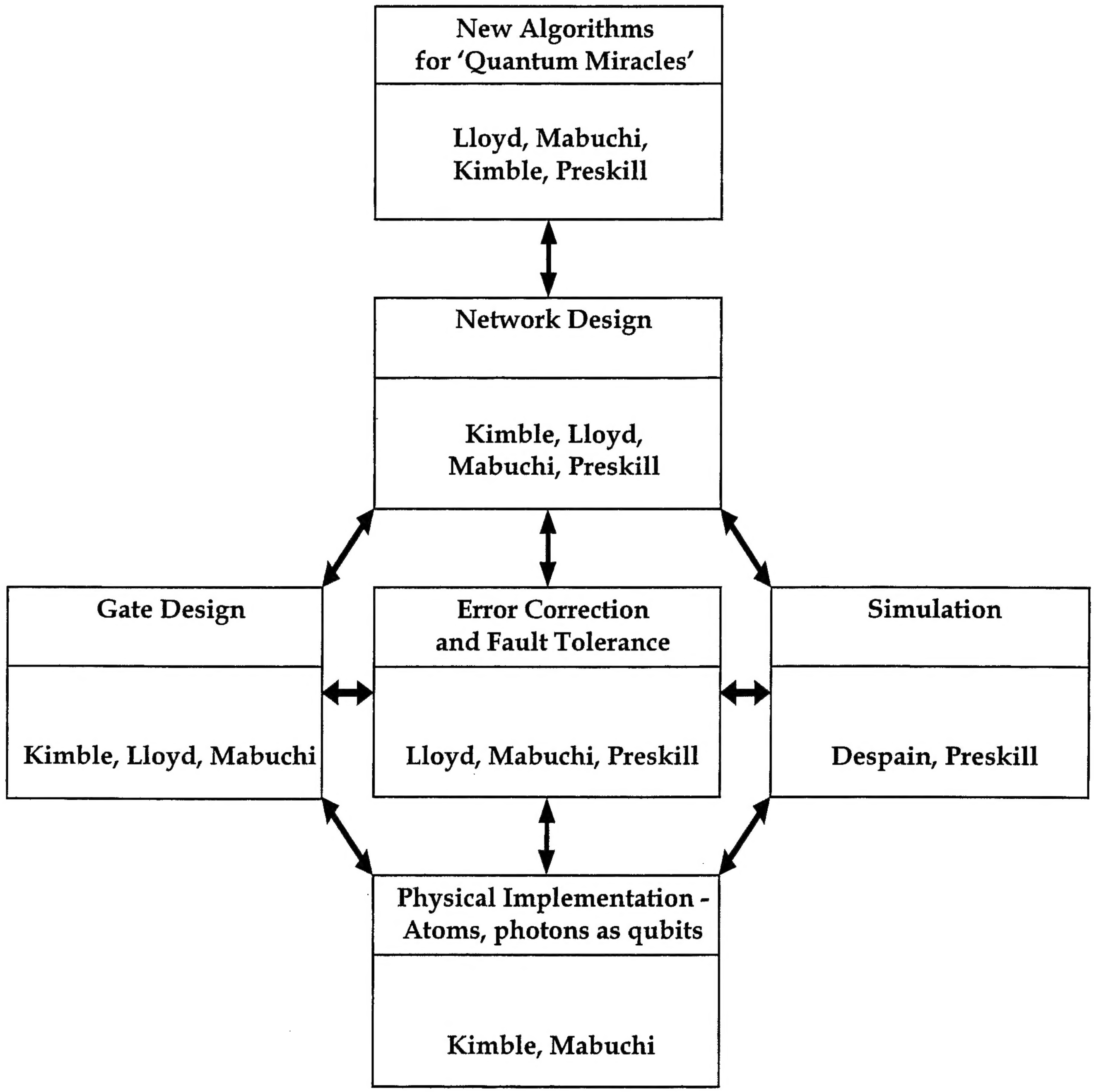

Figure 1 - The QUIC Collaboration

Implementation of Quantum Logic via Cavity Quantum Electrodynamics

A broad program of research has been pursued relating to the implementation of quantum computation using the methods of cavity quantum electrodynamics (cavity QED) to harness optical interactions of single atoms and photons. Cavity QED offers unique advantages over other proposed schemes for quantum information processing, including a principal dissipative channel that can be explicitly monitored, a feature useful for error correction. A major theme of our program has been the development of the tools needed to realize quantum networks (i.e., the quantum internet), with atom-cavity systems linked by high-fidelity optical interconnects. Goals have included the generation of entanglement among multiple cavities to enable quantum cryptography and the realization of fault-tolerant protocols for quantum-state transfer to facilitate distributed quantum computation. We have also investigated a variety of issues pertaining to the scalability and robustness of quantum computation, including new approaches to quantum wiring between qubits and new methods of error correction that are tailored to capitalize on specific mechanisms of decoherence and errors arising from entanglement with external control fields. Although the research has been carried out within the arena of cavity QED, we expect that our results will have applicability to a broad spectrum of implementations of quantum logic.

Quantum Error Correction and Fault-Tolerant Quantum Computation

A quantum computer derives its power from phenomena that are exceptionally vulnerable to the effects of noise and to imperfections in the machine, so that special precautions must be taken to prevent a quantum computer from crashing. New methods and protocols have been developed to improve the efficiency of error recovery and of fault-tolerant quantum gates. Methods of fault-tolerant quantum computing have been adapted to more general error models and to realistic devices. Error correction for analog quantum computation has also been investigated. Again, simulations on classical computers have been performed to test the efficacy of various machine architectures for implementing these error correction schemes. Protocols for experimental realizations of quantum error correction have been developed.

New Quantum Algorithms

Algorithms for both ultra-scale as well as simple (few-bit) quantum computers have been developed with the goal of performing tasks that are not possible on classical devices and which demonstrate exponential speed-ups over classical computers. With respect to few qubit systems, these algorithms are being implemented by programming quantum 'microprocessors' using nuclear magnetic resonance techniques.

Design, Analysis, and Simulation of Quantum Networks

The approach has been to simulate small circuits using a detailed physical model, and then with these results, to validate less detailed and less complex models which can then be used to simulate larger quantum problems beyond the reach of direct classical

simulation. The simulator that has been built simulates a quantum computer at the instruction level, with the quantum registers as state space vectors as described above, and with networks emulated as combinations of these instructions in a hierarchical fashion with basic modules. Building the circuit in this manner allows reuse of functionality and isolation of portions of the circuit for possible optimization. The most detailed models have been based directly on realistic physical systems (e.g., the ion-trap quantum computer), and hence the simulations relate directly to current and planned experiments.

Quantum Feedback Control

A larger framework for quantum error correction has been developed within the setting of a general theory of quantum feedback control. Feedback control implemented in a fully quantum-mechanically coherent fashion can manipulate quantum systems in ways that are not possible using ordinary 'semiclassical' feedback control, and will be important in quantum process control in the construction of quantum machines. This new theory is being implemented within the settings of cavity QED and NMR.

QUIC Accomplishments

Following is a summary of some of the most significant achievements of the QUIC collaboration supported by DARPA and administered by ARO:

Delineation of complexity classes for quantum information processing. In particular, the class BQNP has been discovered, which is the natural quantum analog of the NP class for classical computation.

Investigation of the complexity class QIP ("quantum interactive proof") which is the natural quantum analog of the IP class for classical computation. An important result is that QIP=QIP[1.5]; that is, that one and one half rounds of quantum communication are as powerful as many rounds.

Realization of the trapping of an atom within an optical cavity by employing an auxiliary laser that creates a potential to localize the atom within the cavity. This is an important step toward the realization of quantum logic and quantum networks with atoms and photons.

Demonstration of quantum teleportation for the amplitudes of a quantum optical field, which is relevant to the realization of quantum networks. Extensions of the original theory formulated by QUIC researchers have been made that should enable teleportation of atomic wavepackets when combined with the QUIC efforts in cavity QED.

Formulation of a generalization of "toric codes" to protect quantum information from errors by storing the information in the topological properties of a quantum state of a lattice system defined on a Riemann surface.

Development of new fault-tolerant procedures based on toric coding that can maintain an unknown quantum state with good fidelity indefinitely, as long as the probability of error per elementary qubit is less than about 0.1%. This new result is an improvement by about two orders of magnitude over the accuracy threshold found previously by QUIC researchers.

Application of quantum information theory to improve the precision of quantum-limited measurement.

Discovery of several profound and fundamental aspects of nonlocality in quantum systems such as would be employed for distributed quantum computation and quantum networks.

Development of a method for correcting non-Markovian errors in quantum systems including quantum computers, which is significant for robust quantum machines.

Realization of new quantum algorithms important to quantum simulation.

Performance of a series of seminal experiments using NMR, including the demonstration of a quantum feedback loop, the first experimental confirmation of Greenberger-Horne-Zeilinger (GHZ) correlations, and the first demonstration of a quantum Fourier transform (QFT), a key subroutine in most quantum algorithms.

Development of a theory of universal quantum computation over continuous variables, including a proposal for its realization using simple linear and nonlinear operations.

Development of a theory of quantum dense coding for enhanced channel capacity with continuous quantum variables (e.g., the amplitude and phase of a beam of light).

Development of more efficient quantum digital circuits. These circuits are in the general class of reversible digital logic circuits, so that these results have applicability beyond quantum computing, e.g. very low power classical digital logic.

Introduction and analysis of new measures of quantum-state entanglement, which is fundamental to quantum information processing. This work sheds light on the interpretation of various other entanglement measures, and has also clarified the inherently irreversible nature of the preparation of entangled states.

Demonstration of the trapping of an atom within an optical cavity by implementing a rudimentary quantum servo. A *sensor* detects the motion of a single atom in real time with sufficient bandwidth to trigger an *actuator* that provides a potential for localizing the atom inside an optical cavity.

Proposal for and analysis of a new scheme for the distribution of quantum information by way of *phantom photons*. This protocol increases the probability for successful transmission of quantum information beyond that set by passive losses and is significant

in helping to enable quantum networks for distributed quantum computation and communication.

Development of a parallel quantum computer simulator for Shor's factoring and Grover's database search problems, including quantitative benchmarks for these algorithms.

Investigation of the effectiveness of error correction codes by analyzing a code that corrects a single error per block by encoding one qubit into seven. These computer simulations have been complimentary to theoretical studies in the QUIC group of error correcting codes and fault tolerant computation, and have provided quantitative validation.

Definition of more powerful gates than the controlled-not gate and assessment of their impact on the implementation of the quantum factoring circuit.

Discovery of analog quantum error-correcting routines for continuous quantum variables such as position and momentum.

Development of a novel technique for quantum computation by combining spectral hole burning with adiabatic passage in an optical cavity.

Proposal for and analysis of designs for quantum logic devices using superconducting circuits in quantum regime.

Development of quantum control methods for enhancing stability and reducing decoherence in quantum optical and magnetic resonance spin systems.

Proof that nonlinear quantum mechanics can be used in conjunction with quantum computation to solve NP-complete problems in polynomial time.

Discovery of new algorithms for determining the eigenvalues and eigenvectors of a quantum systems more rapidly than is possible classically.

Analysis of quantum coding and quantum inseparability by use of an information-theoretic approach previously developed by QUIC.

Investigations of quantum copying machines and derivation of a no-cloning uncertainty relation.

Development of an improved quantum search algorithm based on nesting, which relates to better quantum algorithms for NP-complete problems.

Proposal for and analysis of a high efficiency scheme for generating a deterministic bit stream of single photon pulses.

Development of a scheme for the realization of quantum networks utilizing photons and atoms in cavities. Multiple atom-cavity systems located at spatially separated "nodes" would be interconnected via optical fibers to create a quantum internet.

Proof that if quantum error correction and fault-tolerant methods are invoked, it is possible in principle to perform a quantum computation of arbitrary length reliably, if the average probability of error per gate is below a certain critical value. (Similar conclusions were reported by Knill, Laflamme, and Zurek, by Aharonov and Ben-Or, and by Kitaev.)

Development of a scheme for fault-tolerant hardware envisioned by Alexei Kitaev (who developed his idea while visiting the QUIC group), in which the quantum gates exploit non-abelian Aharonov-Bohm interactions among the distantly separated quasiparticles in a suitably constructed spin system.

Discovery that there are noisy quantum channels that convey classical information most efficiently if an alphabet of nonorthogonal signal states is chosen.

Design of algorithms for simple (few-bit) quantum computers, thereby enabling quantum 'microprocessors,' with two or three quantum bits, to perform tasks that are not possible on classical devices.

Development of a number of 'non-standard' techniques for quantum computation, including extending existing adiabatic passage techniques to many particles and to frequency domain methods.

Formulation of a larger framework for quantum error correction by embedding it in a general theory of quantum feedback control. A QUIC proof shows that if feedback control is implemented in a fully quantum-mechanically coherent fashion, then quantum systems can be controlled in ways that are not possible using ordinary 'semiclassical' feedback control.

Reduction of the complexity of simulating a quantum computer. A two-state model has been developed that reduces the complexity of simulating the trapped ion quantum computer exponentially, as has been validated by actual simulation.

Development of the first circuit implementation of the Grover database algorithm for the trapped ion quantum computer.

Inventions

The Atom-Cavity Microscope (ACM)

A new form of microscopy has been demonstrated based upon the coupling of a single atom to an optical cavity. Note that our ACM provides atomic position as a function of time, and hence is a real-time microscopy of the motion of a single atom. Although the initial experiments have been carried out in a high-vacuum apparatus, we

believe that the techniques associated with our new microscopy should be applicable to imaging in chemistry and biology.

Technology Transition:

Methods have been developed to:
- represent qubits in photons, ions and atoms;
- perform logic operations on qubits in traps and cavities, employing laser pulses;
- transmit qubits over distances;
- sequence through many quantum computing steps;
- correct errors; and
- measure results.

All these methods represent technology that have been be transferred to other organizations via reports, products and students.

Technology transfer of quantum computing techniques has occurred through three methods:

- First, results have been made available to interested members of the DOD community through direct contacts, visits and DOD sponsored meetings.
- Second, general results have been publicly available through presentations at conferences, in journals and in web pages.
- Third and most importantly, students, post-docs and visitors have been trained in our laboratories. They are now carrying the technology to other organizations that they have joined.

John Preskill has developed a widely recognized course on quantum information and quantum computation at Caltech. The lecture notes are available on the web at http://www.theory.caltech.edu/people/preskill/ph229.

Final Progress Report

August 12, 1996 through February 11, 2001

Quantum Information and Computation

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B. List of Manuscripts/Publications:

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2. "Quantum State Transfer and Entanglement Distribution Among Distant Nodes in a Quantum Network," J.I. Cirac, P. Zoller, H.J. Kimble and H. Mabuchi, Physical Rev. Letters **78**, No. 16, 3221 (1997).
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C. List of Seminars/Presentations:

1. “Nonclassical Light 20 Years Later: An Assessment of the Voyage into Hilbert Space,” H. J. Kimble, Highlights in Quantum Optics, The Royal Society, London, England (January 29-30, 1997).
2. “Quantum Measurement and Logic with Single Atoms and Photons,” H. J. Kimble, German Physical Society, Mainz, Germany (March 3-6, 1997).
3. “QUIC – Quantum Information and Computation,” H. J. Kimble, University of Innsbruck, Austria (April, 1997).
4. The Cavity QED Circus: Flying Photons, Falling Atoms, and Juggling Atoms,” H. J. Kimble, The Max Planck Institute for Quantum Optics, Garching, Germany (April, 1997).
5. “QUIC - Quantum Information and Computation,” H. J. Kimble, Laboratory for Physical Sciences, University of Maryland, College Park, MD (April 23, 1997).
6. “QUIC - Quantum Information and Computation,” H. J. Kimble, Hanan Rosenthal Memorial Lectureship, Yale University, New Haven CT (April 24-25, 1997).
7. “Quantum Computing,” H. J. Kimble, Advanced Deep Space Systems Development Program & Workshop on Advanced Spacecraft Technologies, Jet Propulsion Laboratory, Pasadena, CA (June 4, 1997).

8. "Strong Interactions of Single Atoms and Photons in Cavity QED," H. J. Kimble, Nobel Symposium 104: Modern Studies of Basic Quantum Concepts and Phenomena, Uppsala, Sweden (June 13-17, 1997).
9. "Quantum Computation - The Plumbing," H. J. Kimble, Scientific Media Briefing, California Institute of Technology, Pasadena, CA (September 17, 1997).
10. "QUIC - Quantum Information and Computation," H. J. Kimble, Fink Symposium, University of Texas, Austin, TX (September 19-21, 1997).
11. "Prospects for Quantum Feedback Control of Atomic Motion in a High-Finesse Optical Cavity," H. Mabuchi, Center for Advanced Studies Workshop on Quantum Control, University of New Mexico, Albuquerque NM (March 4, 1997).
12. "Information Dynamics in Cavity QED," H. Mabuchi, Japan Science and Technology International Symposium on New Techniques in Quantum Measurement, Stanford University, Stanford CA (March 20, 1997).
13. "Information Dynamics in Cavity QED," H. Mabuchi, Center for Advanced Studies Workshop on The Physics of Information, University of New Mexico, Albuquerque NM (April 28, 1997).
14. "Quantum Reality Bytes: Computers and the Quantum Theory of Information," H. Mabuchi, Caltech Alumni Day, Caltech, Pasadena CA (May 17, 1997).
15. "Information Dynamics in Cavity QED," H. Mabuchi, Second Working Group On Quantum Optics And Quantum Computation, Scuola Normale Superiore, Pisa Italy (June 28, 1997).
16. "Information Dynamics in Cavity QED," H. Mabuchi, Institute for Scientific Interchange Workshop On Quantum Computation, Villa Gualino, Torino Italy (June 30, 1997).
17. "Quantum Information Dynamics in Cavity QED," H. Mabuchi, Physical Sciences Seminar, IBM Almaden Research Center, Almaden CA (July 14, 1997).
18. "Information Dynamics in Cavity QED," H. Mabuchi, Institute for Theoretical Atomic and Molecular Physics Workshop On Quantum Information, Harvard University, Cambridge MA (August 14, 1997).
19. "Real-Time Tracking of an Individual Atom's Motion with Quantum-Limited Precision: Principles, Experiment, and Applications," H. Mabuchi, Physics and Astronomy Department Colloquium, University of New Mexico, Albuquerque NM (September 5, 1997).
20. "Real-time tracking of an individual atom's motion in the quantum measurement regime," H. Mabuchi, Optical Society of America Meeting/ILS-XIII, Long Beach, CA (12-17 October 1997).
21. "Feedback Control of Open Quantum Systems," H. Mabuchi, QUIC Seminar, Caltech (April 21, 1997).
22. "Dynamic generation of maximally entangled photon multiplets," H. J. Kimble, Optical Society of America Meeting/ILS-XIII, Long Beach, CA (12-17 October 1997).
23. "Cavity Quantum Electrodynamics with the Whispering Gallery," H.J. Kimble, IEEE Laser & Electro-Optics Society 1997 Annual Meeting, San Francisco, CA (12 November 1997).
24. "QUIC – Quantum Information and Computation," H.J. Kimble, Princeton University, Princeton, NJ (20 November 1997).

25. "Implementing Quantum Logic & Communication via Cavity QED," H.J. Kimble, First International Conference on Unconventional Models of Computation, Center for Discrete Mathematics and Theoretical Computer Science, Auckland New Zealand (5-9 January 1998).
26. "Potentially Exploitable Quantum Phenomena," H.J. Kimble, First NASA International Conference on Quantum Computing and Quantum Communications 1998, Palm Springs, CA (19 February 1998).
27. "Quantum Logic & State Synthesis in Cavity Quantum Electrodynamics," H.J. Kimble, American Physical Society March Meeting, Los Angeles, CA (17 March 1998).
28. "Teleportation of Continuous Quantum Variables," A. Furusawa, Conference on Lasers and Electro-Optics (CLEO)/International Quantum Electronics Conference (IQEC), San Francisco, CA (3-8 May 1998).
29. "Real-time Cavity QED with Single Atoms," C.J. Hood, Conference on Lasers and Electro-Optics (CLEO)/International Quantum Electronics Conference (IQEC), San Francisco, CA (3-8 May 1998).
30. "Physical implementations for quantum communication in quantum networks," S. van Enk, Conference on Lasers and Electro-Optics (CLEO)/International Quantum Electronics Conference (IQEC), San Francisco, CA (3-8 May 1998).
31. "Real-time cavity QED with single atoms," Jun Ye, International Quantum Electronics Conference, San Francisco, CA (18-23 May 1998).
32. "Quantum Manipulation and Measurement of Single Atoms in Optical Cavity QED," Jun Ye, Conference on Precision Electromagnetic Measurements, Washington, D. C. (5-10 July 1998).
33. "Cavity QED – where's the Q?," C. J. Hood, Quantum Optics and Applications of Microcavities and Photonic Crystals Summer Session, Cargèse, Corsica, France (3 August 1998).
34. "The Cavity QED Circus: Juggling Atoms, Flying Photons, and Fantastic Finesse," H. J. Kimble, Nonlinear Optics '98, Kauai, HI (10 August 1998).
35. "Quantum Information enabled by Quantum Optics," H. J. Kimble, Sixth International Symposium on Foundations of Quantum Mechanics in the Light of New Technology (ISQM-Tokyo'98) (24 August 1998).
36. "Quantum Networks for Distributed Quantum Information Processing," H. J. Kimble, Fourth International Conference on Quantum Communications, Measurements, and Computing (QCM'98), Northwestern University, Evanston, IL (22 August 1998).
37. "Quantum Information Processing in Quantum Optics," H. J. Kimble, Mysteries, Puzzles, and Paradoxes in Quantum Mechanics, Gargnano, Italy (30 August 1998).
38. "Coherent Control of Trapped Neutral Atoms," Jun Ye, Trapped Charged Particles and Fundamental Physics, Monterey, CA (30 August – 4 September 1998).
39. "Quantum Teleportation," H. J. Kimble, International Symposium on Epistemological and Experimental Perspectives on Quantum Optics, Vienna, Austria (3 September 1998).
40. "Cavity QED with High-Q Whispering Gallery Modes of Quartz Microspheres," H. J. Kimble, Optical Society of America (OSA) Annual Meeting, Baltimore, MD (4 October 1998).

41. "Cavity QED for quantum logic, communication, and networks," Jun Ye, Optical Society of America 1998 Annual Meeting, Baltimore, MD (4-9 October 1998).
42. "Quantum Networks for Distributed Quantum Computation and Communication," H. J. Kimble, Colloquium, Oklahoma State University (24 October 1998).
43. "Quantum Networks for Distributed Quantum Computation and Communication," H. J. Kimble, Colloquium, University of Arkansas (25 October 1998).
44. "Quantum Computation and Communication – The Promise, the Problems, and the Plumbing," H. J. Kimble, Colloquium, California State University Los Angeles, Los Angeles, CA (11 November 1998).
45. "Quantum Computation and Communication – The Promise, the Problems, and the Plumbing," H. J. Kimble, Colloquium, Princeton University, Princeton, NJ (19 November 1998).
46. "Quantum Information Science – An Invasion of Alien Bits from Hilbert Space," H. J. Kimble, John Newton Dodd Prestige Lecture, University of Otago, Dunedin, New Zealand (10 December 1998).
47. "Quantum Networks for Quantum Communication and Computation," H. J. Kimble, Australasian Conference on Optics, Lasers and Spectroscopy (ACOLS'98), University of Canterbury, Christchurch, New Zealand (14 December 1998).
48. "Genuine Quantum Teleportation," H. J. Kimble, Twenty-ninth Winter Colloquium on the Physics of Quantum Electronics, Snow Bird, UT (3 January 1999).
49. "Quantum Information Science – The Promise, the Problems, and the Plumbing," H. J. Kimble, Physical Chemistry Seminar, University of California Los Angeles (11 January 1999).
50. "Quantum Information Science – The Promise, the Problems, and the Plumbing," H. J. Kimble, Colloquium, University of Arizona, Tucson, AZ (14 January 1999).
51. "Quantum Information Science – The Promise, the Problems, and the Plumbing," H. J. Kimble, Winter Colloquium, University of Chicago, Chicago, IL (21 January 1999).
52. "Quantum Information and Computation," H. J. Kimble, 1999 American Association for the Advancement of Science (AAAS) Annual Meeting and Science Innovation Exposition, Anaheim, CA (21 January 1999).
53. "The Quantum Optics Circus – Flying Photons and Acrobatic Atoms," H. J. Kimble, Colloquium, University of New Mexico, Albuquerque, NM (5 March 1999).
54. "Quantum Information Science – The Promise, the Problems, and the Plumbing," H. J. Kimble, University of California Riverside, Riverside, CA (11 March 1999).
55. "The Quantum Optics Circus," H. J. Kimble, California Institute of Technology Discovery Weekend, Pasadena, CA (16 April 1999).
56. "Cavity QED with Cold Qubits," D. W. Vernooy, Southwest Quantum Information and Technology (SQuInT), Albuquerque, NM (30 April 1999).
57. "Quantum Communication and Computation in Quantum Optics," H. J. Kimble, Hewlett-Packard Internal Conference on Optoelectronics and RF Technology, Santa Rosa, CA (3 May 1999).
58. "Towards Quantum Computation Network in Optical Cavity QED," J. Ye, Conference on Lasers and Electro-Optics / Quantum Electronics and Laser Science (CLEO/QELS) Conference '99, Baltimore, MD (26 May 1999).

59. "The Quantum Internet," H. J. Kimble, Fourteenth International Conference on Laser Spectroscopy (ICOLS99), Innsbruck, Austria (7 June 1999).
60. "The Quantum Internet," H. J. Kimble, Gordon Conference on Atomic Physics, Plymouth State College, Plymouth, NH (5 July 1999).
61. "Cavity QED – The Promise and the Plumbing," H. J. Kimble, Southwest Quantum Information and Technology Conference (SquInT), University of California – Santa Barbara, CA (3 August 1999)
62. "Trapping Atoms in Cavity QED: Experiments in the Strong Coupling Domain", T. Lynn, Gordon Research Conference on Quantum Control of Atomic and Molecular Motion, Plymouth State College, Plymouth, NH (2 August 1999).
63. "Quantum Information and Computation," H. J. Kimble, Quantum Computing Program Review, U. S. Army Research Laboratory, Adelphi, MD (30 August 1999)
64. "Quantum Information Processing in Quantum Optics," H. J. Kimble, Mysteries, Puzzles, and Paradoxes in Quantum Mechanics: Workshop on Entanglement and Decoherence, Palazzo Feltrinelli, Gargnano, Italy (20 September 1999)
65. "The Quantum Internet," S. J. van Enk, Colloquium, California State University – Long Beach, Long Beach, CA (20 September 1999).
66. "The quantum optics circus – flying photons, acrobatic atoms, and teleported Tuataras," H. J. Kimble, 1999 Optical Society of America/15th Interdisciplinary Laser Science Conference (OSA/ILS-XV), Santa Clara, CA (27 September 1999).
67. "The Quantum Optics Circus: Flying photons, Acrobatic Atoms & Teleported Tautaras," H. J. Kimble, Physics Colloquium, California Institute of Technology, Pasadena, CA (9 December 1999).
68. "Toward a deterministic state control and generalized measurement via cavity QED," H. J. Kimble, NEC Workshop on Quantum Cryptography, NEC Institute, Princeton, NJ (13 December 1999).
69. "Single atoms bound in orbit by single photons," H. J. Kimble, 30th Winter Colloquium on the Physics of Quantum Electronics, Snowbird, UT (10 January 2000).
70. "The Quantum Internet," S. J. van Enk, Bell Labs, Murray Hill, NJ (14 January 2000).
71. "The cavity QED circus – flying photons, acrobatic atoms, and teleported Tuataras," H. J. Kimble, Alumni Fund Council Meeting, California Institute of Technology, Pasadena, CA (22 January 2000).
72. "The Quantum Internet," S. J. van Enk, California State University – Los Angeles, Los Angeles, CA (3 February 2000).
73. "The cavity QED circus – flying photons, acrobatic atoms, and teleported Tuataras," H. J. Kimble, University of Texas-Austin, Austin, TX (8 March 2000).
74. "The cavity QED circus – flying photons, acrobatic atoms, and teleported Tuataras," H. J. Kimble, Texas A&M University (10 March 2000).
75. "Quantum Logic with cavity QED," S. J. van Enk, Harvard-ITAMP workshop on Applications of Slow Light, Boston, MA (4 April 2000).
76. "Atoms in Cavities," H. J. Kimble, Quantum Electronics and Laser Science Conference (QELS), San Francisco, CA (8 May 2000).

77. “Real-Time Tracking and Trapping of Single Atoms in Cavity QED,” H. J. Kimble, Invited presentation at XVII International Conference on Atomic Physics (ICAP), Florence, Italy, (June 2000).
78. “Real-Time Tracking and Trapping of Single Atom in Cavity QED,” H. J. Kimble, Invited talk at the Institute of Physics and Astronomy, Aarhus University, Aarhus, Denmark (10 June 2000).
79. “Shedding light on Bose-Einstein condensates,” D. M. Stamper-Kurn, Quantum Fluids and Solids Conference, Minneapolis, MN (June 2000).
80. “Peeking and poking at a quantum fluid,” D. M. Stamper-Kurn, Thesis prize talk at the DAMOP conference, Storrs, CT (June 2000).
81. “Single atoms bound in orbit by single photons,” C. J. Hood, Visit to Center for Spintronics and Quantum Computation, University of California, Santa Barbara, CA June 2000).
82. “Single atoms bound in orbit by single photons,” C. J. Hood, Invited talk at Modern Problems in Laser Physics 2000 (MPLP 2000), Novosibirsk, Russia (5 July 2000).
83. “Single atoms bound in orbit by single photons,” C. J. Hood, Visit to Semiconductor Group, University of Munich, Munich, Germany (14 July 2000).
84. “Real-time manipulation of single, strongly coupled atoms,” C. J. Hood, Invited talk at Laser Physics 2000 (LPHYS 2000), Bordeaux, France (19 July 2000).
85. “Single atoms bound in orbit by single photons,” C. J. Hood, Visit to CNET/France Telecom Labs, Bagneux, France (26 July 2000).
86. “Single atoms bound in orbit by single photons,” C. J. Hood, Visit to RAND Corporation, Santa Monica, CA (10 August 2000).
87. “Overview of Kimble Group research activities,” C. J. Hood, Mini-workshop, Caltech – UCSB, California Institute of Technology, Pasadena, CA (14 August 2000).
88. “The Quantum Internet - Distributed Quantum networks for Computation & Communication,” H. J. Kimble, Invited presentation at the Quantum Computing Symposium, Baltimore, MD (28 August 2000).
89. “Cavity QED with Trapped Atoms,” H. J. Kimble, Invited presentation for the European Conference on Lasers and Electro-optics/ International Quantum Electronics Conference 2000 (CLEO-Europe/IQEC 2000), Nice Acropolis, France (14 September 2000).
90. “Cavity QED with Cold Atoms,” H. J. Kimble, Invited presentation at Mysteries, Puzzles, and Paradoxes in Quantum Mechanics, Garda Lake, Italy (September 2000).
91. "Trapped Atoms and Cavity-QED," H. C. Nägerl, Invited seminar at Los Alamos National Laboratory, Los Alamos, NM (20 September 2000).
92. “Quantum Teleportation” and “Cavity QED”, H. J. Kimble, Invited presentation at Chaos, Decoherence, and Quantum Entanglement (Pan-American Advanced Study Institute), Ushuaia, Argentina (9-20 October 2000).
93. “Cavity QED with Single Atoms and Photons – Toward Deterministic Control of Quantum Dynamics,” H. J. Kimble, Invited presentation for the JILA/NIST Colloquium, Boulder, CO (8 November 2000).
94. “Quantum Information Science – The Promise, the Problems, and the Plumbing,” H. J. Kimble, Invited talk at the NSF Math and Physical Sciences Directorate Distinguished Scientists Lecture Series, Washington, DC (20 November 2000).

95. "Atoms in Optical Cavities," H. J. Kimble, Invited presentation for The Quantum Theory Centenary, Berlin, Germany (11 December 2000).

D. Degrees/Awards and Honors:

Degrees - Quentin Turchette, Ph.D., California Institute of Technology, June 1997
Degrees - Hideo Mabuchi, Ph.D., California Institute of Technology, June 1998
Degrees – David W. Vernooy, Ph.D., California Institute of Technology, June 2000
Degrees – Christina J. Hood, Ph.D., California Institute of Technology, June 2000
David Vernooy – National Sciences and Engineering Research Council (NSERC), 1997 Science and Engineering Scholarship
Christina Hood – New Zealand Vice-Chancellor's Committee, William Georgetti Fellowship
Theresa Lynn – NSF Graduate Fellowship
Michael Chapman – Assistant Professor of Physics, Georgia Institute of Technology
Hideo Mabuchi – Assistant Professor of Physics, California Institute of Technology
Dan Stamper-Kurn – Assistant Professor of Physics, University of California, Berkeley
H. J. Kimble, Ph.D. – Max Born Award of the Optical Society of America, Rochester, NY, 22 October 1996
H.J. Kimble, Ph.D. – Named William L. Valentine Professor at the California Institute of Technology; Visiting Professor of Physics, University of Innsbruck, March-April, 1997
H. J. Kimble awarded the "*1998 International Quantum Communication Award for Outstanding Experimental Advances in the areas of Quantum Measurements, Cavity QED, and Quantum Logic*", presented at the Fourth International Conference on Quantum Communication, Measurement, and Computing held at Northwestern University, Evanston, Illinois by the Research Institute of Tamagawa University.
Degrees - Hideo Mabuchi, Ph.D., California Institute of Technology, June 1998
Degrees – David W. Vernooy, Ph.D., California Institute of Technology, June 2000

E. Report of Inventions: None

F. Technology Transfer: H.J. Kimble – presentation at Laboratory for Physical Sciences, University of Maryland; Interactions with NSA personnel concerning quantum computation and communication.

J. Preskill, Ph.D., Co-Principal Investigator, Caltech

A. List of Participating Scientific Personnel:

John Preskill, Ph.D., Co-Principal Investigator
Dr. Alexei Kitaev, Ph.D., Visiting Associate
Postdoctoral Scholars: Dr. Christopher Fuchs, Dr. Michael Nielsen
Graduate Research Assistant: David Beckman

Graduate Students: Andrew Landahl, Daniel Gottesman, Srinivas Aji, John Cortese, Sumit Daftuar

Undergraduate Students: Jarah Evslin, Sham Kakade, Eric Dennis, Walt Ogburn

Visitors/Collaborators: Eric Dennis (UCSB), Daniel Gottesman (LANL), Charles Bennett (IBM), Herb Bernstein (Hampshire College), Sam Braunstein (University of Wales), Carlton Caves (University of New Mexico), David DiVincenzo (IBM), David Meyer (UCSD), Asher Peres (Technion), Lei Poo (Cambridge University), Ruediger Schack (University of London), Peter Shor (AT&T), John Smolin (IBM), Nolan Wallach (UCSD), Bill Wootters (Williams College), Howard Barnum (Hampshire College), Ike Chuang (IBM), Julia Kempe(UC Berkeley), Emanuel Knill (LANL), Raymond Laflamme (LANL), Ben Schumacher (Kenyon College), Sergey Bravyi (Landau Institute for Theoretical Physics, Moscow), John Watrous (University of Montreal), Michael Freedman (Microsoft Research), Greg Kuperberg (UC Davis), Dr. Martin Plenio, Dr. Tal Mor, Dr. Peter Hoyer, Dr. Debbie Leung.

B. List of Manuscripts/Publications:

1. "Nonorthogonal Quantum States Maximize Classical Information Capacity," C. A. Fuchs, Physical Review Letters **79** (6), 1162-1165 (1997).
2. "Optimal Eavesdropping in Quantum Cryptography. I. Information Bound and Optimal Strategy," C. A. Fuchs, N. Gisin, R. B. Griffiths, C. S. Niu, and A. Peres, Physical Review A **56** (2), 1163-1172 (1997).
3. "Entanglement-Enhanced Classical Communication on a Noisy Quantum Channel," C. H. Bennett, C. A. Fuchs, and J. A. Smolin, in Quantum Communication, Computing and Measurement, edited by O. Hirota, A. S. Holevo, and C. M. Caves (Plenum Press, NY, 1997), pages 79-88.
4. "Efficient Computations of Encoding for Quantum Error Correction," R. Cleve and D. Gottesman, Phys. Rev. A **56** (1997) 76.
5. "A Theory of Fault-Tolerant Quantum Computation," D. Gottesman; see also quant-ph/9702029.
6. "Stabilizer Codes and Quantum Error Correction," D. Gottesman; see also quant-ph/9705052.
7. "Reliable Quantum Computers," J. Preskill, *Proceedings of the Royal Society of London* A **454**, 385 (1998).
8. "Quantum Computing: Pro and Con," J. Preskill, *Proceedings of the Royal Society of London* A **454**, 469 (1998).
9. "Fault-Tolerant Quantum Computation," J. Preskill, in *Introduction to Quantum Computation and Information*, eds. H.-K. Lo, S. Popescu, and T. Spiller (World Scientific, 1998).
10. "Optimal Universal and State-dependent Quantum Cloning," D. Bruss, D. P. DiVincenzo, A. Ekert, C.A. Fuchs, C. Macchiavello, and J. A. Smolin, Phys Rev A **57** (3), (1998); see also quant-ph/9705038.

11. "Entanglement of Assistance," P. DiVincenzo, C. A. Fuchs, H. Mabuchi, J. A. Smolin, A. Thapliyal, and A. Uhlmann, in *Quantum Computing and Quantum Communications: Springer-Verlag Lecture Notes in Computer Science*, 1509, ed. C. P. Williams (Springer-Verlag, Berlin, 1998).
12. "A Quantum Analog of Huffman Coding," S. L. Braunstein, C. A. Fuchs, D. Gottesman, and H.-K. Lo, in Proceedings 1998 IEEE International Symposium on Information Theory (IEEE Information Theory Society, Cambridge, MA, 1998), 353.
13. "Robust Solutions to hard problems," J. Preskill, Nature **391**, 631 (1998
14. "Making Weirdness Work: Quantum Information and Computation," J. Preskill, *Proceedings of the 1998 IEEE Aerospace Conference*, ed. R. Profet (IEEE, 1998).
15. "Optimal Universal and State-dependent Quantum Cloning," D. Bruss, D. P. DiVincenzo, A. Ekert, C. A. Fuchs, C. Macchiavello, and J. A. Smolin, Phys. Rev. A **57**, 2368 (1998).
16. "A Quantum Analog of Huffman Coding," S. L. Braunstein, C. A. Fuchs, D. Gottesman, and H.-K. Lo, in *Proceedings 1998 IEEE International Symposium on Information Theory* (IEEE Information Theory Society, Cambridge, MA, 1998), p 353.
17. "Quantum Nonlocality without Entanglement," C. H. Bennett, D. P. DiVincenzo, C. A. Fuchs, T. Mor, E. Rains, P. W. Shor, J. A. Smolin, and W. K. Wootters, Phys. Rev. A **59**, 1070 (1999).
18. "Cryptographic Distinguishability Measures for Quantum Mechanical States," C. A. Fuchs and J. van de Graaf, IEEE Transactions on Information Theory **45**, 1216 (1999).
19. "Topological quantum computation," R. W. Ogburn and J. Preskill, in *Quantum Computing and Quantum Communications*, ed. C. P. Williams, Springer-Verlag Lecture Notes in Computer Science, Volume 1509 (1999).
20. "Battling decoherence: the fault-tolerant quantum computer," J. Preskill, Physics Today **52**, 24 (1999)
21. "Quantum information and physics: some future directions," J. Preskill, Journal of Modern Optics **47**, 127-137 (2000).
22. "Quantum information and precision measurement," A. M. Childs, J. Preskill and J. Renes, Journal of Modern Optics **47**, 155-176 (2000).
23. "Complete quantum teleportation using nuclear magnetic resonance," M. A. Nielsen, E. Knill and R. Laflamme, Nature **396**, 52 (1998).
24. "Information transmission through a noisy quantum channel," H. Barnum, M. A. Nielsen and B. Schumacher, Phys. Rev.A **57**, 4153 (1998).
25. "Conditions for a Class of Entanglement Transformations," M. A. Nielsen, Phys. Rev. Lett. **83**, 436 (1999).
26. "A partial order on the entangled states," M. A. Nielsen, to appear in Phys. Rev. Lett. (1999).
27. "Continuity bounds for entanglement," M. A. Nielsen, Phys. Rev. A **61**, 064301 (2000); see also quant-ph/9908086.
28. "Probability distributions consistent with a mixed state," M. A. Nielsen, Phys. Rev. A **62**, 052308 (2000); see also quant-ph/9909020.
29. "On quantum fidelities and channel capacities," H. Barnum, E. Knill and M. A. Nielsen, submitted to IEEE Transactions on Information Theory (1998).

30. "Experimental Proposal for Achieving Superadditive Communication Capacities with a Binary Quantum Alphabet," J. R. Buck, S. J. van Enk, and C. A. Fuchs, Phys. Rev. A **61**, 032309 (2000).
31. "Criteria for Continuous-Variable Quantum Teleportation," Samuel L. Braunstein, Christopher A. Fuchs, and H. J. Kimble, Journal of Modern Optics **47**, 267 (2000).
32. "Quantum Mechanical Channels," C. A. Fuchs, to appear in *Quantum Information and Quantum Computation: Selected Annotated Papers*, eds. C. Macchiavello, G. M. Palma, and A. Zeilinger (World Scientific, Singapore, 1999).
33. "Entanglement Is Super … But Not Superluminal," S. J. van Enk and C. A. Fuchs, *Instantaneous Action at a Distance in Modern Physics: "Pro" and "Contra"*, ed. A. E. Chubykalo (Nova Science Publishers, Commack, NY, 1999), 407.
34. "Just Two Nonorthogonal Quantum States," C. A. Fuchs, *Quantum Communication, Computing, and Measurement 2*, eds. P. Kumar, G. M. DAriano, O. Hirota (Kluwer Academic/Plenum, New York, 2000), 11.
35. "Information Gain vs. State Disturbance in Quantum Theory," C. A. Fuchs, Fortschritte der Physik 46, 535(1998). Reprinted in *Quantum Computation: Where Do We Want to Go Tomorrow?*, ed. S. L. Braunstein (Wiley-VCH Verlag, Berlin, 1999).
36. "Quantum Probability from Decision Theory?," H. Barnum, C. M. Caves, J. Finklestein, C. A. Fuchs, and R. Schack, *Proceedings of the Royal Society of London Series A* **456**, 1175-1182 (2000); see also quant-ph/9907024.
37. "Quantum codes on a lattice with boundary," S. B. Bravyi and A. Yu. Kitaev (to be submitted); see also quant-ph/9811052.
38. "Fredholm determinants for hyperbolic diffeomorphisms of finite smoothness," A.Yu. Kitaev, Nonlinearity **12**, 141 (1999).
39. "Multiparticle entanglement and its applications to cryptography," J. Kempe, Phys. Rev. A **60**, 910 (1999).

C. List of Seminars/Presentations:

1. "Bosonic Quantum Codes for Amplitude Damping," Debbie Leung, QUIC Seminar, Caltech (September 18, 1996).
2. "Mixed State Entanglement and the Quantum Channel Capacity," John Smolin, of IBM Watson Research Center, QUIC Seminar, Caltech, (November 15, 1996).
3. "Reliable Quantum Computers," J. Preskill, QUIC Seminar, Caltech (December 4, 1996).
4. "Quantum Computing with Noisy Gates," J. Preskill, ITP Conference on Quantum Coherence and Decoherence, Santa Barbara (December 17, 1996).
5. "Classical Information on Quantum Channels," C. Fuchs, University of Innsbruck Physics Seminar, Innsbruck, Austria (December 23, 1996).
6. "Quantum Information and Quantum Computation," J. Preskill, Earnest Watson Public Lecture, Caltech (January 15, 1997).
7. "My Favorite Open Problems in Quantum Information," C. Fuchs, Information Physics Seminar, University of New Mexico, Albuquerque, New Mexico, (March 3, 1997).

8. “Classical Information on Quantum Channels,” C. Fuchs, AT\&T Seminar on Quantum Computation and Error Correction, AT\&T Bell Labs, Murray Hill, New Jersey (March 19, 1997).
9. “Putting Weirdness to Work,” J. Preskill, Physics Colloquium, University of New Mexico (March 28, 1997).
10. “Putting Weirdness to Work,” J. Preskill, Physics Colloquium, Cal. State University, Pomona (April 4, 1997).
11. “Fault-Tolerant Quantum Computation by Anyons”, Alexei Kitaev, of Landau Institute, Moscow, QUIC Seminar, Caltech (April 9, 1997).
12. “My Favorite Open Problems in Quantum Information,” C. Fuchs, Quantum Information and Computation (QUIC) Institute Seminar, California Institute of Technology, Pasadena, California (April 14, 1997).
13. “Classical Information on Quantum Channels---Nonorthogonal States: Child of Nature, Friend of Man,” C. Fuchs, Mini-Workshop on Information Physics, Center for Advanced Studies, University of New Mexico, Albuquerque, New Mexico, (April 30, 1997).
14. “Information Transmission through Noisy Quantum Channels,” M. Nielsen, of University of New Mexico, QUIC Seminar, Caltech (May 9, 1997).
15. “Nonorthogonal Quantum States Maximize Classical Information Capacity,” C. Fuchs, Atomic Physics Seminar, The University of Texas, Austin, Texas, (May 15, 1997).
16. “Nonorthogonal Quantum States Maximize Classical Information Capacity,” C. Fuchs, First Killam Workshop on Quantum Information Theory, Universite de Montreal, Montreal, Canada (May 27, 1997).
17. “Classical Capacities of a Quantum Channel,” C. Fuchs, Workshop on Quantum Computation 1997, Institute for Scientific Interchange, Turin, Italy (June 30, 1997).
18. “Topological Quantum Computation,” J. Preskill, Workshop on Quantum Computation, Torino, Italy, (July 3, 1997).
19. “Quantum Copying,” Chi-Sheng Niu, of Carnegie-Mellon University, QUIC Seminar, Caltech (August 28, 1997).
20. “Basic Quantum Mechanics” and “Sending Classical Information on Quantum Channels,” C. Fuchs, DIMACS Quantum Computing Tutorial and Workshop, Princeton University, Princeton, NJ, (August 11-15, 1997).
21. “The Basics of Quantum Communication Channels,” C. Fuchs, Electronic Engineering and Computer Systems Seminar, University of Wales, Bangor, Wales, (September 15, 1997).
22. “Surprises in Sending Classical Information on Quantum Channels,” C. Fuchs, Royal Holloway College Physics Seminar, London, England (September 19, 1997).
23. “Nonorthogonal Quantum States Maximize Classical Information Capacity,” C. Fuchs, Electrical and Computer Engineering Seminar, University of California at Los Angeles, Los Angeles, California (October 3, 1997).
24. “QUIC Theory,” J. Preskill, DARPA Ultrascale Program PI Meeting, Estes Park, CO (October 14, 1997).
25. “Alice, Bob, and Eve in Quantumland,” Dr. Tal Mor, of University of Montreal, QUIC Seminar, Caltech (October 27, 1997).

26. “Fault-Tolerant Quantum Computation,” J. Preskill, Issues in Quantum Computation and Information, Novartis Foundation, London (November 7, 1997).
27. "Fault-Tolerant Quantum Computation," J. Preskill, Issues in Quantum Computation and Information, Novartis Foundation, London, UK (7 November 1997).
28. “Quantum Information Theory,” C. Fuchs, Michelson Lecture Series, Case Western Reserve University, Cleveland, OH, three lectures (2-6 February 1998).
29. “Quantum Entanglement: What Good Is It?,” C. Fuchs, Physics Colloquium, Case Western Reserve University, Cleveland, OH (5 February 1998).
30. “Quantum-enhanced Classical Communication,” C. Fuchs, IBM Research Division Physics Seminar, Yorktown Heights, NY (9 February 1998).
31. "Topological Quantum Computation," J. Preskill, 1st NASA International Conference on Quantum Computing and Quantum Communications, Palm Springs, CA (17 February 1998).
32. “Classical-Enhanced Quantum Communication,” C. Fuchs, 1st NASA International Conference on Quantum Computing Quantum Communications (NASA QCQC’98), Palm Springs, CA (18 February 1998).
33. “Quantifying Quantum Entanglement,” C. Fuchs, Quantum Communication Seminar, Tamagawa University, Tokyo, Japan (7 March 1998).
34. "Putting Weirdness to Work: Quantum Information and Computation," J. Preskill, March Meeting of the American Physical Society: Invited Session, Frontiers in Physics, Los Angeles, CA (19 March 1998).
35. "Making Weirdness Work: Quantum Information and Computation," J. Preskill, IEEE Aerospace Conference, Plenary Address, Snowmass, CO (23 March 1998).
36. "Putting Weirdness to Work," J. Preskill, Physics Colloquium, Harvey Mudd College, Claremont, CA (7 April 1998).
37. “Quantum-Enhanced Classical Communication,” C. Fuchs, Seminar, Max Planck Institute for Quantum Optics, Garching, Germany (7 April 1998).
38. "Battling Decoherence: the Fault-Tolerant Quantum Computer," J. Preskill, Caltech Physics Research Conference, Pasadena, CA (16 April 1998).
39. "Putting Weirdness to Work," J. Preskill, Spring Meeting of the American Association of Physics Teachers, Pomona, CA (25 April 1988).
40. “Quantum NP,” Alexei Kitaev, Hebrew University, Jerusalem, Israel (2 June 1998).
41. "Reliable Quantum Computing," J. Preskill, ARO/NSA Kickoff Meeting: Demonstration of and Algorithmic Development for Quantum Computation, Bowie, MD (10 June 1998).
42. "Battling Decoherence: the Fault-Tolerant Quantum Computer," J. Preskill, Symposium on Gauge Theory, Cosmology, and Fundamental Physics, Imperial College, London, UK (10 July 1998).
43. “The fault-tolerant quantum computer,” J. Preskill, 4th International Conference on Quantum Communication, Measurement, and Computing, Northwestern University (26 August 1998).
44. “Battling decoherence: the fault-tolerant quantum computer,” J. Preskill, University of Arizona Physics Colloquium (16 September 1998).
45. “Anyonic quantum computaion,” A. Kitaev, Microsoft Research, Redmond, WA (22 September 1998).

46. "Battling decoherence: the fault-tolerant quantum computer," J. Preskill, University of California - Santa Barbara Physics Colloquium (20 October 1998).
47. "Battling decoherence: the fault-tolerant quantum computer," J. Preskill, University of California - Davis Math/Physics Colloquium (26 October 1998).
48. "Just Two Nonorthogonal Quantum States," C. Fuchs, Information Physics Seminar, University of New Mexico, Albuquerque, NM (29 October 1998).
49. "Battling decoherence: the fault-tolerant quantum computer," J. Preskill, University of Oregon Physics Colloquium (5 November 1998).
50. "Battling decoherence: the fault-tolerant quantum computer," J. Preskill, IBM Almaden Research Center Colloquium (6 November 1998).
51. "Adventures in fault tolerance," J. Preskill, Microsoft Research seminar (7 December 1998).
52. "Quantum NP," A. Kitaev, Microsoft Research, Redmond, Washington (8 December 1998).
53. "Quantum computation," M. Nielsen, Seminar at the Lawrence Livermore National Laboratory (10 December 1998).
54. "The Role of Quantum Information for Physics," C. Fuchs, Southwest Quantum Information and Technology (SQUINT) Network Kickoff Meeting (17 December 1998).
55. "The future of quantum information theory," J. Preskill, Southwest Quantum Information and Technology Network Meeting, IBM Almaden Research Center (18 December 1998).
56. "On the structure of the entangled states," M. Nielsen, Seminar at the Los Alamos National Laboratory (10 January 1999).
57. "On the structure of the entangled states," M. Nielsen, Seminar at the Los Alamos National Laboratory (12 January 1999).
58. "On the structure of the entangled states," M. Nielsen, Seminar at IBM Almaden Research Center (18 January 1999). "Quantum Information: What is It? What Good is It?," C. Fuchs, AMO Physics Seminar, University of Wisconsin at Madison (11 February 1999).
59. "Quantum NP," A. Kitaev, Second Workshop on Algorithms in Quantum Information Processing, De Paul University, Chicago, Illinois (21 January 1999).
60. "Topological quantum codes and anyons," A. Kitaev, University of California – Davis, Davis, California (26 January 1999).
61. "Quantum complexity classes," A. Kitaev, Steklov Mathematical Institute, Moscow, Russia (9 February 1999).
62. "On the structure of the entangled states," M. Nielsen, Seminar at Microsoft Research (15 February 1999).
63. " 'Nonlocality without Entanglement' and the Communication Capacity of Nonorthogonal Quantum States," C. Fuchs, Microsoft Research Seminar, Redmond, Washington (22 February 1999).
64. "Quantum teleportation by Nuclear Magnetic Resonance," M. Nielsen, Seminar at the Boston NMR Quantum Computing Conference (27 February 1999).
65. "Battling decoherence: the fault-tolerant quantum computer," J. Preskill, University of California – Los Angeles Math Colloquium (4 March 1999).

66. "Quantum Information, Quantum Channels," C. Fuchs, MIT Electrical Engineering and Computer Science Special Seminar, Cambridge, Massachusetts (15 March 1999).
67. "Quantum Teleportation: Using Entanglement as a Resource," C. Fuchs, Amherst College Physics Colloquium, Amherst, Massachusetts (2 April 1999).
68. "Battling decoherence: the fault-tolerant quantum computer," J. Preskill, California State University - Long Beach Physics Colloquium (19 April 1999).
69. "Battling decoherence: the fault-tolerant quantum computer," J. Preskill, Arizona State University Physics Colloquium (22 April 1999).
70. "Fermions for quantum computation," A. Kitaev, First Annual Workshop of the Southwest Quantum Information and Technology (SQuInT) Network, University of New Mexico, Albuquerque, NewMexico (2 May 1999).
71. "Putting weirdness to work: quantum information and computation," J. Preskill, American Physical Society Northwest Section Conference, University of British Columbia (21 May 1999).
72. "Battling decoherence: the fault-tolerant quantum computer," J. Preskill, University of California – Santa Barbara Math Colloquium (27 May 1999).
73. "Majorization and its applications to quantum information theory," M. Nielsen, Seminar Series at the California Institute of Technology (June 1999).
74. "The structure of the entangled states," Michael Nielsen, Workshop on Complexity, Computation and the Physics of Information, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom (July 1999).
75. "On quantum dynamics," Michael Nielsen, Quantum Information Processing 1999 (QIP '99), Montreal, Canada (December 1999).

D. Awards and Honors:

Degrees – Daniel Gottesman, Ph.D., California Institute of Technology, June 1997

Christopher Fuchs awarded the "*Albert A. Michelson Postdoctoral Prize Lectureship*", presented at Case Western Reserve University, Cleveland, Ohio, by the Case Western Reserve University Physics Department.

E. Report of Inventions: None

E. Technology Transfer: None

Steven Koonin, Ph.D., Co-Principal Investigator, Caltech

A. List of Participating Scientific Personnel:

Dr. Steven Koonin, Ph.D., Co-Principal Investigator
Postdoctoral Scholars: Dr. Nicolas Cerf, Dr. Chris Adami
Graduate Student: David Bacon, Robert M. Gingrich
Undergraduate Students: Scott Noble, Francois Lekien

B. List of Manuscripts/Publications:

1. "Negative Entropy and Information in Quantum Mechanics," N. J. Cerf and C. Adami, Phys. Rev. Lett. **79**, 5194 (1997); see also KRL-MAP-191 and quant-ph/951202200.
2. "Negative Entropy in Quantum Information Theory," N. J. Cerf and C. Adami, in: *New Developments on Fundamental Problems in Quantum Physics*, ed. M. Ferrero and A. van der Merwe, Fundamental Theories of Physics **81**, 77 (Kluwer, Dordrecht, 1997); see also quant-ph/9610005.
3. "Information theory of quantum entanglement and measurement," N. J. Cerf and C. Adami, Physica D **120**, 62 (1998); see also *Proceedings of the 4th Workshop on Physics and Computation*, Boston 1996, ed. T. Toffoli, M. Biafore, and J. Leao (New England Complex Systems Institute, Cambridge, MA, 1996), p. 65; see also KRL-MAP-199 and quant-ph/9605039.
4. "Physical Reality and Quantum Paradoxes," C. Adami and N. J. Cerf, (submitted to Lecture Notes in Computer Science, Springer-Verlog, 1998); see also KRL-MAP-204.
5. "Entropic Bell Inequalities," N. J. Cerf and C. Adami, Phys. Rev. A **55**, 3371 (1997); see also KRL-MAP-205 and quant-ph/9608047.
6. "von Neumann Capacity of Noisy Quantum Channels," C. Adami and N. J. Cerf, Phys. Rev. A **56**, 3470 (1997); KRL-MAP-206 and quant-ph/9609024.
7. "Information-Theoretic Interpretation of Quantum Error-Correcting Codes," N. J. Cerf and R. Cleve, Phys. Rev. A **56**, 1721 (1997); KRL-MAP-209 and quant-ph/9702031.
8. "Accessible Information in Quantum Measurement," N. J. Cerf and C. Adami, submitted to Phys. Rev. Lett..; see also KRL-MAP-207 and quant-ph/9611032.
9. "Monte Carlo simulation of quantum computation," N. J. Cerf and S. E. Koonin, *Proceedings of the IMACS Seminar on Monte Carlo Methods, Brussels, April 1-3, 1997*, Mathematics and Computers in Simulation **47**, 143 (1998); see also KRL-MAP-212 and quant-ph/9703050.
10. "Optical simulation of quantum logic," N. J. Cerf, C. Adami, and P. Kwiat, Phys. Rev. A **57**, R1477 (1998); see also KRL-MAP-211 and quant-ph/9706022.
11. "Entropic bounds on coding for noisy quantum channels," N. J. Cerf, Phys. Rev. A **57**, 3330 (1998); see also KRL MAP-215 and quant-ph/9707023.
12. "Quantum Conditional Operator and a Criterion for Separability," N. J. Cerf, C. Adami, and R. M. Gingrich, submitted to Phys. Rev. A. [KRL MAP-217 and quant-ph/9710001]
13. "Asymmetric quantum cloning machines," N. Cerf, Acta Physica Slovaca **48**, 115 (1998).
14. "Quantum extension of conditional probability," N. J. Cerf and C. Adami, submitted to Phys. Rev. A **60**, 893 (1999).
15. "Quantum cloning and the capacity of the Pauli channel," N. J. Cerf, submitted to Phys. Rev. Lett. (quant-ph/9803058)
16. "Information-theoretic aspects of quantum copying," N. J. Cerf, in *Quantum Computation and Quantum Communication, Proceedings of the 1st NASA International Workshop* , ed. C.P. Williams, LNCS 1509 (Springer-Verlag: Berlin, 1999), 218.

17. "What information theory can tell us about quantum reality," C. Adami and N. J. Cerf, in *Quantum Computation and Quantum Communication, Proceedings of the 1st NASA International Workshop* , ed. C.P. Williams, LNCS 1509 (Springer-Verlag: Berlin, 1999), 258.
18. "Quantum computation with linear optics," C. Adami and N. J. Cerf, in *Quantum Computation and Quantum Communication, Proceedings of the 1st NASA International Workshop* , ed. C.P. Williams, LNCS 1509 (Springer-Verlag: Berlin, 1999), 391.
19. "Nested quantum search and NP-complete problems," N. J. Cerf, L. K. Grover and C. P. Williams, in *Applicable Algebra in Engineering, Communication and Computing: Special issue for the Dagstuhl Seminar on Quantum Algorithms* (Springer-Verlag; quant-ph/9806078)

C. List of Seminars/Presentations:

1. "An introduction to quantum information theory," N. J. Cerf, Center for Nonlinear Phenomena and Complex Systems, Brussels University, Belgium (12 November 1997).
2. "What information theory can tell us about quantum reality," C. Adami, lst NASA International Conference on Quantum Computing and Quantum Communications (QCQC '98), Palm Springs, CA (17-20 February 1998).
3. "Quantum computation with linear optics," C. Adami, 1st NASA International Conference on Quantum Computing and Quantum Communications (QCQC '98), Palm Springs, CA (17-20 February 1998).
4. "Information-theoretic aspects of quantum copying," N. J. Cerf, 1st NASA International Conference on Quantum Computing and Quantum Communications (QCQC '98), Palm Springs, CA (17-20 February 1998).
5. "Pauli cloning machines and their many-dimensional generalization," N. J. Cerf, Dagstuhl Seminar on Quantum Algorithms, Wadern, Germany (10-15 May 1998).
6. "Nested quantum search," N. J. Cerf, Dagstuhl Seminar on Quantum Algorithms, Wadern, Germany (10-15 May 1998).

D. Awards and Honors:

Caltech President's Fund Award, 1997.
N.J. Cerf, C. Adami, C. P. Williams, and M. Zak.

S. E. Koonin awarded the *"Department of Energy E. O. Lawrence Award for Excellence in Physics, 1998"*, presented in Washington, D.C. by the Department of Energy.

II. MIT, Seth Lloyd, Ph.D., Co-Principal Investigator

A. List of Participating Scientific Personnel

Seth Lloyd, Ph.D. Co-Principal Investigator

Postdoctoral Scholars: Dr. H. Kwang, Dr. Lorenza Viola

Graduate Students: Daniel Abrams, Rick Nelson, Hyuk-Sang Kwan, Yaakov Weinstein, Yun Kang

Visiting Graduate Students: Wim van Damm, Christoff Durr

Undergraduate Student: B. Hoffman

Visitors: Murray Gell-Mann, David Cory, Selim Shahriar, Samuel Braunstein, Hans Mooij, Jean-Jacques E. Slotine.

B. List of Manuscripts/Publications:

1. "Capacity of the Noisy Quantum Channel," Physical Review A **55**, 1613-1622 (1997).
2. "Simulation of Many-Body Fermi Systems on a Universal Quantum Computer," with Dan Abrams, Phys. Rev. Lett. **79**, 2586-2589 (1997).
3. "Quantum-Mechanical Maxwell's Demon," Phys Rev A **56**, 3374 (1997).
4. "Controllability and Observability of Quantum Systems," submitted to Physical Review Letters, March 13, 1997.
5. "Universe as Quantum Computer," Complexity 3, p. 32, 1997.
6. "Analog Quantum Error Correction," S. Lloyd, and J.J.-E. Slotine, Phys. Rev. Lett. **80**, 4088 (1998).
7. "Unconventional Quantum Computing Devices," S. Lloyd, in *Unconventional Models of Computation: Proceedings of the First International Conference*, eds. C.S. Calude, J. Casti, M.J. Dinneen (Springer, Singapore, 1998).
8. "Microscopic Analogs of the Greenberger-Horne-Zeilinger Experiment," S. Lloyd, Phys. Rev. A **57,** R1473 (1998).
9. "Experimental Realization of a Quantum Algorithm," S. Lloyd, I.L. Chuang, L.M.K. Vandersypen, X. Zhou, and D.W. Leung, Nature **393**, 143 (1998).
10. "Dynamical Suppression of Decoherence in Two-State Quantum Systems," S. Lloyd and L. Viola, Phys. Rev. A **58**, 2733 (1998).
11. "Nonlinear Quantum Mechanics Implies the Polynomial-Time Solution of NP-Complete and # P Problems," S. Lloyd and D. Abrams, Phys. Rev. Lett. **81**, 3992 (1998).
12. "Quantum Computing," S. Lloyd, G. Brassard, I. Chuang, and C. Monroe, *Proceedings of the National Academy of Sciences USA 95*, 11032 (1998).
13. "Universal Quantum Simulators: correction," S. Lloyd, Science **279**, 1113 (1998).
14. "Computational Complexity and Physical Law," S. Lloyd and D. Abrams, in *Proceedings of the NASA Conference on Quantum Computation and Quantum Coherence* (Springer, Singapore, 1998).
15. "Quantum Computing: Stepping Closer to Reality," S. Lloyd, and N. Forbes, Computers in Physics 12, No. 1, 8 (1998).
16. "Quantum Computation over Continuous Variables," S. Lloyd, and S. Braunstein, Phys. Rev. Lett. **82**, 1784 (1999).
17. "Dynamical Decoupling of Open Quantum Systems," S. Lloyd, L. Viola, and E. Knill, Phys. Rev. Lett. **82**, 2417 (1999).
18. "Computational complexity and physical law," S. Lloyd and D.S. Abrams, Lect. Notes. Comput. Sc. **1509,** 167 (1999).

19. "Josephson persistent current qubit," S. Lloyd, J.E. Mooij, T.P. Orlando, et al. Science **285**, 1036 (1999).
20. "Quantum algorithm providing exponential speed increase for finding eigenvalues and eigenvectors," Daniel S. Abrams and Seth Lloyd, Phys. Rev. Lett. **83**, 5162 (1999).
21. "Experimental Demonstration of Coherent Quantum Feedback," S. Lloyd, R. Nelson, Y. Weinstein, and D. Cory, *Quantum Communication, Computing, and Measurement 2*, eds. P. Kumar, G. M. DAriano, O. Hirota (Kluwer Academic/Plenum, New York, 2000), 353.
22. "Decoherence Control in Quantum Information Processing: Simple Models," S. Lloyd and L. Viola, *Quantum Communication, Computing, and Measurement 2*, eds. P. Kumar, G. M. DAriano, O. Hirota (Kluwer Academic/Plenum, New York, 2000), 59.
23. "Experimental demonstration of fully coherent quantum feedback," S. Lloyd, R. J. Nelson, Y. Weinstein, and D. Cory, Phys. Rev. Lett. **85**, 3045 (2000).
24. "Quantum feedback with weak measurements," S. Lloyd and J.-J. E. Slotine, Phys. Rev. A **62**, 2307 (2000).
25. "Quantum search without entanglement," S. Lloyd, Phys. Rev. A **61**, 010301 (2000).
26. "Experimental demonstration of Greensberger-Horne-Zeilinger correlations using nuclear magnetic resonance," R. J. Nelson, D. Cory and S. Lloyd, Phys. Rev. A **61**, 022106 (2000).
27. "Implementation of the quantum Fourier transform," S. Lloyd, Y. Weinstein, M. A. Pravia, E. M. Fortunato, and D. Cory, Phys. Rev. Lett. **86**, 1889 (2001).

C. List of Seminars/Presentations:

1. "Quantum Information and Computation," Cambridge Seminar on Quantum Mechanics, Imperial College, London (January 17, 1997).
2. "Quantum Computation and Quantum Control, " Oxford University Physics Seminar, Clarendon Lab, Oxford (January 20, 1997).
3. "Quantum Inference, " Hewlett Packard Conference on Time Series Prediction, BRIMS, Bristol (January 22, 1997).
4. "Quantum Computation," Hewlett Packard Conference on Time Series Prediction, BRIMS, Bristol (January 23, 1997).
5. "Quantum Computers," White House Science Advisory Office Seminar Series, RAND, Washington (February 6, 1997).
6. "Quantum Computation," Northeastern University Physics Colloquium, Boston (February 11, 1997).
7. "Quantum Computation, a Summary," QUIC Get-Together, Caltech, Pasadena (February 17, 1997).
8. "A Quantum-Mechanical Maxwell's Demon," Gordon Conference on Nonequilibrium Thermodynamics, Ventura (February 18, 1997).
9. "Quantum Lattice Gases," MIT Math Department Fluid Mechanics Seminar (March 4, 1997).
10. "Quantum Computation," Courthauld Institute Colloquium, NYU Math Department, New York (March 24, 1997).

11. "Quantum Information and Computation," University of Maryland Physics Colloquium, Maryland (April 1, 1997).
12. "Quantum Computation in the Solid State," Harvard Applied Sciences Departmental Seminar (April 4, 1997).
13. "Quantum Computation," Texas Instruments Colloquium, Dallas (April 17, 1997).
14. "Optical Methods for Quantum Computing," MIT Research Lab for Electronics Seminar, Cambridge (May 6, 1997).
15. "A Microscopic Analog of the Greenberger-Horne-Zeilinger Experiment," Quantum Information and Measurement Conference, Pisa, Italy (June 26, 1997).
16. "Nuclear Magnetic Resonance Quantum Computation," Institute for Scientific Interchange Workshop on Quantum Computation, Torino, Italy (July 1, 1997).
17. "Quantum Computation and Communication," Finmeccanica, Rome (July 2, 1997).
18. "A Microscopic Analog of the Greenberger-Horne-Zeilinger Experiment," International Workshop on Quantum Coherence, Northeastern University, Boston (July 12, 1997).
19. "Discrete Wigner Functions," MIT Quantum Physics Seminar Series (July 26, 1997).
20. "Making Quantum Systems Compute," Workshop on Experimental Realizations of Quantum Logic, Harvard, Cambridge (August 5, 1997).
21. "Quantum Computation," S. Lloyd, National Academy of Sciences Frontiers of Science Meeting, Irvine (November 1997).
22. "Quantum Computation and Quantum Control," S. Lloyd, MIT Electrical Engineering and Computer Science Colloquium (December 1997).
23. "Quantum Computation," S. Lloyd, Keynote speach,International Workshop on Unconventional Computation Devices, Auckland, New Zealand (January 1998).
24. "Nonlinear Quantum Mechanics Allows the Rapid Solution of NP-Complete Problems," Dan Abrams, Palm Springs Quantum Computation conference (February 1998).
25. "Review of Quantum Computation, " S. Lloyd, International Workshop on Quantum Computation and White Noise, Meijo University, Nagoya, Japan (June 1998).
26. "Quantum Communication," S. Lloyd, International Workshop on Quantum Computation and White Noise, Meijo University, Nagoya, Japan (June 1998).
27. "Quantum Control," S. Lloyd, International Workshop on Quantum Computation and White Noise, Meijo University, Nagoya, Japan (June 1998).
28. "Quantum Mechanical Engineering," S. Lloyd, International Workshop on Quantum Computation and White Noise, Meijo University, Nagoya, Japan (June 1998).
29. "Quantum Information Processing," S. Lloyd, Plenary talk, Workshop on Quantum Computation and Quantum Optics, Benasque, Spain (July 1998).
30. "Experimental Demonstration of a Quantum Feedback Loop," S. Lloyd, University of New Mexico Mechanical Engineering Seminar, New Mexico (August 1998).
31. "Review of Recent Developments in Quantum Information Processing," S. Lloyd, Santa Fe Institute Seminar, Santa Fe, New Mexico (August 1998).
32. "Quantum Chaos and Decoherence," S. Lloyd, Los Alamos Systems Seminar (August 1998).
33. "Quantum Simulation," S. Lloyd, European Commission Pathfinder Conference, Helsinki, Finland (September 1998).

34. "Recent Developments in Quantum Computation," S. Lloyd, Boston University Physics Colloquium (October 1998).
35. "Introduction to Quantum Computation," S. Lloyd, Leonardo da Vinci dinner, Massachusetts Institute of Technology (October 1998).
36. "Quantum Computation and Quantum Communication," S. Lloyd, University of Massachusetts Physics Colloquium (October 1998).
37. "Quantum Feedback Control," S. Lloyd, Brockettfest, Harvard University (October 1998).
38. "Quantum Computation over Continuous Variables," S. Lloyd, New England Complex Systems Institute Conference, Nashua, New Hampshire (October 1998).
39. "Quantum Computers," S. Lloyd, Banquet Speech, IEEE Nuclear Science Symposium and Medical Imaging Conference, Toronto (November 1998).
40. "Fundamental Physical Limits to Quantum Computation," S. Lloyd, Boston University Computer Science Seminar (November 1998).
41. "Experimental Demonstration of Coherent Quantum Feedback," R. Nelson, QCM98, Fourth International Conference on Quantum Communication, Measurement, and Computing, Evanston, Illinois (August 1998).
42. "Decoherence Control in Quantum Information Processing: Simple Models," L. Viola, QCM98, Fourth International Conference on Quantum Communication, Measurement, and Computing, Evanston, Illinois (August 1998).
43. "Quantum Computation," S. Lloyd, Knight Fellows Seminar, Massachusetts Institute of Technology (December 1998).
44. "Quantum Computation over Continuous Variables," S. Lloyd, Plenary Talk, PQE99, Physics of Quantum Electronics, Snowbird, UT (January 1999).
45. "Quantum Computation," S. Lloyd, Brookhaven National Laboratory Colloquium (February 1999).
46. "Quantum Computation and Negative Probabilities," S. Lloyd, Nuclear Magnetic Resonance Quantum Computation Conference, Massachusetts Institute of Technology (February 1999).
47. "Ultimate physical limits to computation," S. Lloyd, Gordon Conference on Modern Developments in Thermodynamics, Castelveccio Pascoli, Italy (April 1999).
48. "Quantum-mechanical engineering," S. Lloyd, Massachusetts Institute of Technology Mechanical Engineering colloquium (May 1999).
49. "Future of quantum computing," S. Lloyd, National Academy of Sciences Workshop on Foundations of Computer Science, Woods Hole (May 1999).
50. "Quantum computing: past, present, and future," S. Lloyd, Javanfest, Columbia University (May 1999).
51. "Quantum correlations without entanglement," Seth Lloyd, Newton Institute Workshop on Quantum Information, Cambridge, United Kingdom (10 July 1999).
52. "Ultimate Physical Limits to Computation," Seth Lloyd, Newton Institute Workshop on Entanglement and Quantum Information Processing, Cambridge, United Kingdom (27 July 1999).
53. "Quantum Computers," Seth Lloyd, Knight Journalism Fellows seminar, Massachusetts Institute of Technology, Cambridge, MA (20 September 1999).
54. "Quantum Computers," Seth Lloyd, International Conference on Complex Systems, New England Complex Systems Institute, Nashua, NH (6 October 1999).

55. "Quantum Process Control," Seth Lloyd, NSF Quantum Computing Meeting, Arlington, VA (27 October 1999).
56. "Ultimate Physical Limits to Computation," Seth Lloyd, Moses Seminar, Massachusetts Institute of Technology, Cambridge, MA (29 November 1999).

D. Report of Inventions:

1. Developed quantum error-correction algorithm for analog systems.
2. Developed novel quantum feedback control technique for the coherent control of quantum systems. This technique was successfully implemented experimentally using nuclear magnetic resonance techniques in November, 1997.
3. Used quantum information processing techniques to create a design for molecular heat engines and refrigerators. Experimental tests scheduled in early 1998.

E. Technology Transfer: With E. Berman, initiated a start-up company, Quantum Technologies, Inc., whose goal is to use techniques developed for programming highly parallel quantum computers in the design of classical highly parallel computers capable of delivering significant speed ups over existing machines for problems of pattern recognition, multiple object tracking, simulation of fluid flows, and advanced materials design.

III. USC, Alvin Despain, Ph.D., Co-Principal Investigator

A. List of Participating Scientific Personnel
Alvin Despain, Ph.D., Co-Principal Investigator
Graduate Students: Kevin Obenland, Joong-Seok Moon, Stelian Alupoaei

B. List of Manuscripts/Publications:

1. "Parallel Quantum Computer Simulator," A. Despain and K. M. Obenland, *Proceedings of High Performance Computing1998, Boston, Massachusetts, USA*, ed. A. Tetner (Society for Computer Simulation, San Diego, 1998).
2. "Parallel Quantum Computer Simulator," A. Despain and K. M. Obenland, *Proceedings of Department of Defense High Performance Computing Modernization Users Group Conference, Houston, Texas, USA* (1998).
3. "Simulating the Effect of Decoherence and Inaccuracies on a Quantum Computer." K. M. Obenland, in *Proceedings NASA Conference on Quantum Computation and Quantum Communication* (1998).
4. "Using Simulation to Assess the Feasibility of Quantum Computing," Kevin M. Obenland, Ph.D. Thesis, University of Southern California (May 1998).

C. List of Seminars/Presentations:

1. "High Performance Computing," Boston, Mass., April 5-9, 1997.
2. "Simulating the Effect of Decoherence and Inaccuracies on a Quantum Computer," Kevin Obenland, NASA Conference on Quantum Computation and Quantum Communication, Palm Springs CA (February 1998).
3. "A Parallel Quantum Computer Simulator," Kevin Obenland, High Performance Computing '98, Boston, MA (April 1998).
4. "Simulating the Effect of Decoherence and Inaccuracies on a Quantum Computer," Kevin Obenland, Ultra Scale Program Principal Investigators Meeting, Tucson AZ (April 1998).
5. "Parallel Quantum Computer Simulation," Kevin Obenland, DoD High Performance Computing Users Group Conference, Houston, TX (June 1998).

D. Awards and Honors:
Kevin M. Obenland, Ph.D., University of Southern California, June 1998